



Human mobility, cognition and GISc

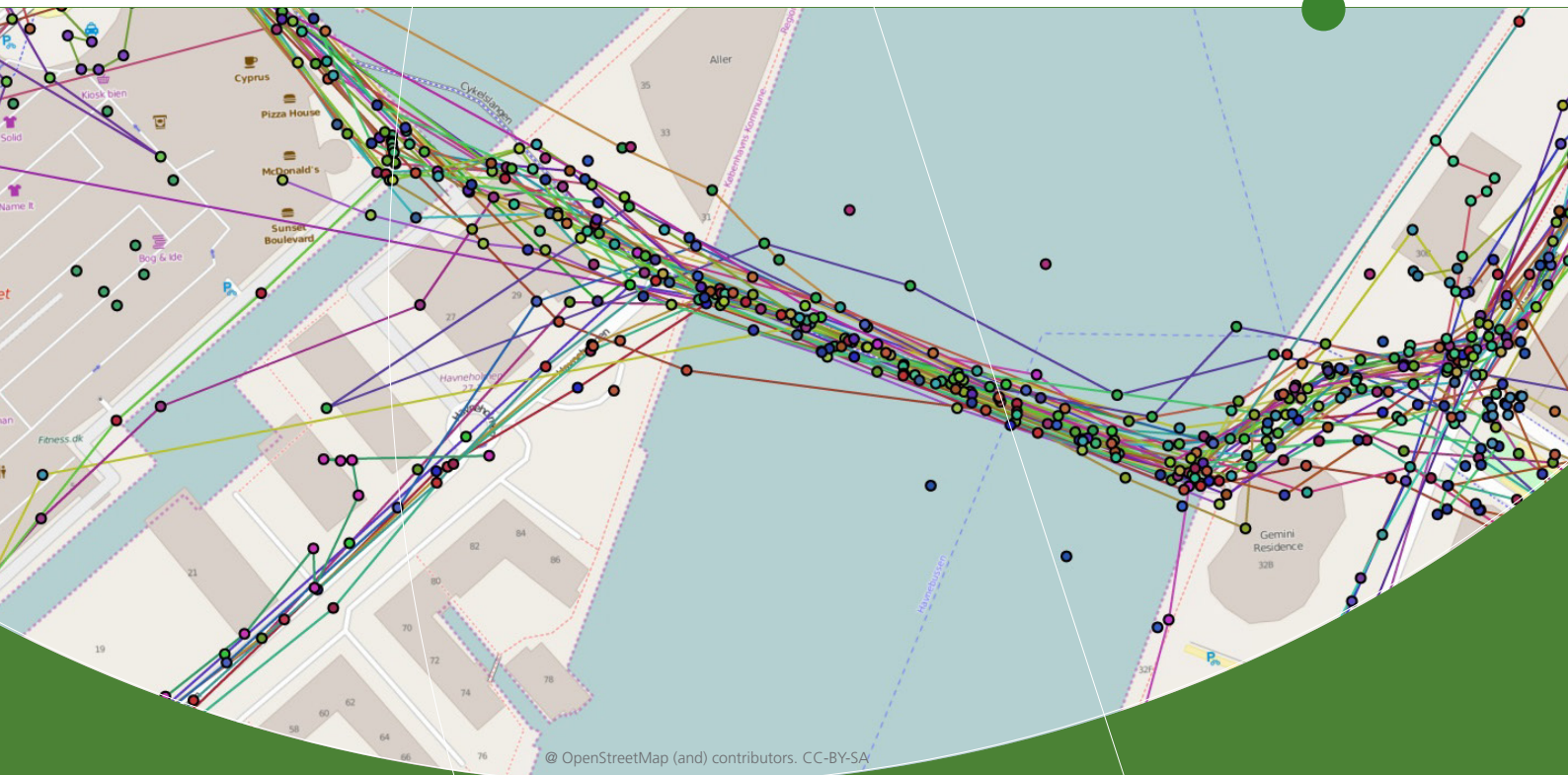
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Hans Skov-Petersen (ed.)

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Preface

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Welcome to Human Mobility, Cognition and GISc' - a conference hosted by the University of Copenhagen on November 9, 2015. The present document encloses the abstracts contributed by five invited speakers and eight submitted as responses to a public call made on June 1st 2015.

In GIS and related sciences (GISc) registration and analysis of human behavior and development of technologies to back us up during our daily activities has a long history behind. Such activities include navigation and wayfinding. At the same time a lot of effort has been spend to investigate and conceptualize the psychological/ cognitive and neurophysiological background of our spatial behavior - including our abilities to perceive, memorize, apply and communicate spatial knowledge.

It is the aim of the conference to bring together professionals from cognitive, analytical and geo-technical sciences (including psychologists, anthropologists, geographers, engineers, and computer scientists) for the mutual development of future concepts for experimenting with, recording, analyzing, simulating, visualizing, and communicating data and information regarding humans' spatial behaviour.

The conference is part of an international PhD course financed by a donation of the Faculty of Science of the University of Copenhagen.

The present document constituted by abstracts authored by the conferences' invited speakers and members of the scientific board, and submissions made after an open call. In the call the following (not exclusive) list of topics was suggested:

- Wayfinding and navigation
- Agent based simulation and modelling (ABM)
- Movement analysis
- Emerging and classic technologies for recording movement
- Visualisation of moving objects
- Spatial perception and memory
- Efficient structures for storing movement data
- Legibility of space
- Experimental settings for spatial behaviour (in situ and in silico)
- Spatial and navigational communication

I would like to thank the conferences' scientific board for taking active part in the preparation of the programme of the conference and for reviewing submitted abstracts. Board members include:

- Professor Daniel R. Montello from University of California, Santa Barbara
- Professor Robert Weibel from University of Zürich
- Senior Lecturer Patrick Laube from Zürich University of Applied Sciences
- Group leader Tobias Meilinger from The Max-Planck-Institute for Biological Cybernetics in Tübingen
- Associate Professor Steffan van Der Spek from Technical University of Delft



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Invited speakers

Social Wayfinding

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Keywords: *Navigation, Social Wayfinding, Wayfinding Communication*

Wayfinding is the planning and reasoning involved in efficient navigation. It serves in figuring out where you are, where you want to go, and how you should go to get there. Typically being oriented partly to the distal environment beyond immediate sensorimotor access, it invokes higher-level cognitive systems including mental representations of the environment (cognitive maps). Wayfinding is not just a solitary cognitive act, however, nor a matter of the surrounding physical environment. It involves other people—concurrently and in the past. This involvement is pervasive and fundamental, and includes people's acts, their cultural and technological influences, even their mere presence. Although understanding social aspects are essential to understanding wayfinding, they are quite under-recognized and under-researched. I discuss in detail instances of social wayfinding in which other people directly or indirectly influence or attempt to influence the specific routes that navigators choose when traveling. My colleagues and I attempt to understand these instances by organizing them within a framework based on the degree, nature, and time frame of the social influence.

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Figure 1: The pattern of the labyrinth at Chartres Cathedral.



Figure 2: A local offers wayfinding assistance during the Mongol Rally.

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Interdisciplinarity makes us MOVE: What we can learn from other sciences in mobility research

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Keywords: mobility research, movement analysis, European research network, space utilization, probabilistic movement models

The objective of this talk is to show, based on a number of examples, how concepts, theoretical models and methods from different disciplines can be usefully exchanged to the benefit of what is available in the 'toolbox' of movement analysis. The assumption, however, is not that just because people move, animals move, and vehicles move, and because we are tracking all of them by GPS, we may treat all of these 'moving objects' alike, ultimately striving for one generic solution. I am not trying to advocate the "one size fits all" approach. Instead, I will try to show how methods and models that are beneficially used in one domain may be usefully adapted to other disciplines. Sometimes, very simply, a particular discipline may have developed a solution to a problem that has not been found yet in another discipline; which may give rise to a potential knowledge transfer, adaptation to the specificities of the target discipline included.

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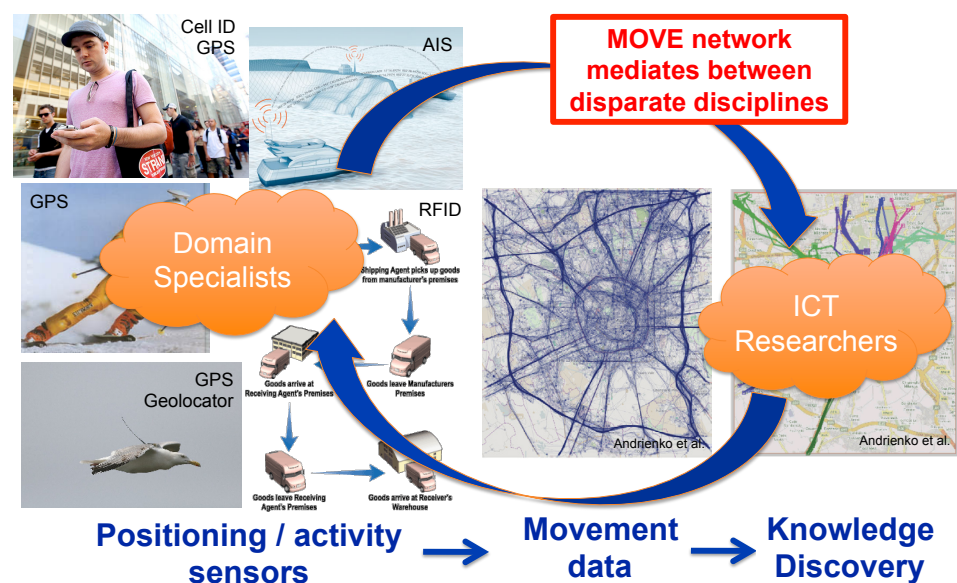


Figure 1: The key idea of the MOVE network – mediating between methods-oriented researchers (ICT, GIScience) and domain scientists (planners, animal ecologists etc.) in order to facilitate the development of novel methods for knowledge discovery from movement data.

I will start off by reviewing the MOVE project (Knowledge Discovery from Moving Objects), a project that was pursued from 2009 to 2013 as a so-called COST Action under the umbrella of the EU COST Program. MOVE wasn't a closed research project in the proper sense. Rather, it was an open research network whose main objective was to facilitate research collaboration between researchers in disparate disciplines dealing with whole-body movement, thus establishing a network of ICT researchers (from CS, GIScience) on the one hand and domain specialists (urbanists, transportation scientists, animal ecologists) on the other hand, in order to enable the development of novel methods for knowledge discovery from moving object data. MOVE has been very successful in setting up a highly interdisciplinary

network in movement research, possibly the largest worldwide at the time, largely because of its promise of exchanging ideas between disciplines. Several breakthrough algorithms have been developed by members of the MOVE network and a large number of publications generated. The website (move-cost.info) shows various videos and presentations of these highlights. My talk will review and illustrate some of these examples as well as the success factor that led to these.

In the second part of my talk, I will try to show where I believe imports of methods used in other disciplines (e.g. animal ecology) might help the analysis of human mobility. I will draw upon experiences made in a project that we currently pursue in studying mobility and activity patterns of older adults in the context of research on healthy aging.

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How do people memorize and recall spatial knowledge within their city of residency?

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Keywords: *Navigation, Route knowledge, Survey knowledge, City of residency, map*

People use “route knowledge” to navigate to targets along familiar routes and “survey knowledge” to determine (by pointing, for example) a target’s metric location. We examined within which coordinate systems route and survey knowledge is represented in memory. Data suggests that navigators memorize survey knowledge of their city of residency (Fig1) within a single, north-oriented reference frame learned from maps (1). However, when they recall this knowledge while located within the city, they spontaneously adjusted this knowledge towards their current body orientation and location relative to the recalled area – probably to have the information ready for later action (2). Contrary to survey knowledge, route knowledge of one’s home city was memorized in different representations relying on multiple, local, street-based coordinate systems presumably learned from navigation (3). When recalling this knowledge to plan a route, navigators concentrate on turns and employ a “when-in-doubt-follow-your-nose” default strategy in order to not get lost (4). Taken together, our results suggest that people coordinate multiple representations of their surrounding environment and adjust these to their current situation.



Figure 1: Virtual Tübingen is a computer model of the city center of Tübingen. In our experiments Tübingen inhabitants were teleported to locations within Virtual Tübingen and conducted route and survey tasks. (Illustration: Martin Breidt/Max Planck Institute for Biological Cybernetics)

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From Patterns to Processes – Bridging the Semantic Gap in Computational Movement Analysis

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Keywords: *Computational Movement Analysis, trajectories, semantic gap, KDD and data mining, spatio-temporal GIS.*

People move in spacetime. The data volumes documenting such movement grow rapidly given almost ubiquitous tracking technologies. The talk first introduces Computational Movement Analysis as the data mining related, interdisciplinary research field tackling the challenge of analyzing and enriching those movement data volumes (Laube 2014, Fayyad et al. 1996).

Whereas Computational Movement Analysis has made much progress in structuring movement data and finding movement patterns, understanding the meaning of the found patterns remains difficult. The talk first illustrates why it is so hard getting from movement patterns to an understanding of the processes governing that movement. To this end, the talk refers to the concept of the semantic gap between the low-level patterns produced by computers and the high-level interpretations we humans need to understand the underlying processes (Galton 2005, Smeulders et al. 2000). A first reason why the semantic gap prevails in Computational Movement Analysis lies in method development that is mostly tools-driven, and not so much problem-driven. A second reason is a general lack of metadata, which is typically missing with trajectory data sets, but would capture the crucial semantics needed for validating the found patterns and bridging the semantic gap.

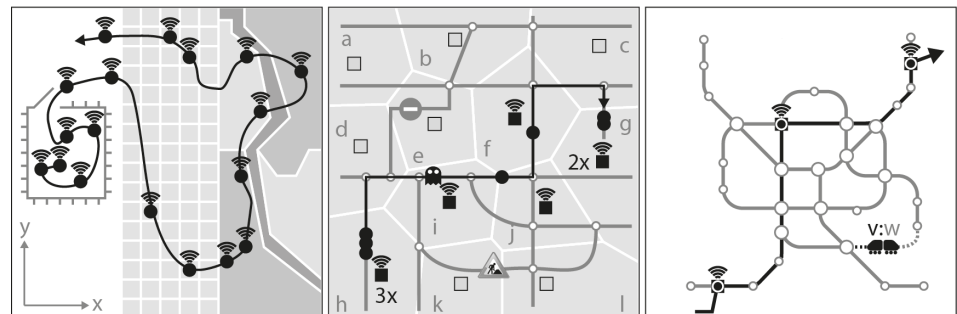


Figure 1: Movement traces embedded in movement spaces. Computational Movement Analysis increasingly focusses on the semantics of the actual movement processes: Leisurely walking through a park, surfing the web whilst riding a bus, or commuting on the metro.

The talk then proposes strategies for bridging the semantic gap. These include the development of context-aware movement analysis methods, the conceptualization of process patterns rather than trajectory geometry patterns (Bleisch et al. 2014), and experiment-oriented movement analysis including not just location sensors but also additional sensors such as accelerometers and gyrometers. The talk concludes with an outlook towards emerging movement analysis topics (Laube 2015).

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Cognitive Aspects of Movement in Urban Design

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Keywords: Urban Design, Tracking, Cognition, Space Syntax, 3-step analysis, Stepping Stones, Landmarks, People

People have an objective when moving around: a goal, a purpose or a destination. Seldom people just wander around for no reason, even when indicating to use intuition.

Choices are made to reach the objective: mode(s) of transportation and route. Some choices are made in advance, prior to departure, other choices are made on the way or even in real-time. A huge proportion of our choices is based on earlier experience with the physically built environment (prior knowledge), interpretation of what is expected (logic), personal preferences and personal habitats (back-ground). Some choices are made obviously, many choices are made unconsciously. But what drives our choices? Efficiency? Costs? Time? Quality? Safety?

The Built Environment provides a framework for our movement: Movement is limited to the infrastructure, i.e. street network and paths offered. Pedestrians have most freedom but are despite limited physically and legally: we cannot walk through walls or cross private property. Trains and trams are limited to the rail infrastructure. Every means of transportation has it's own network, although some parts of the networks can be used by multiple modes.



Figure 1: Map based solely on GPS tracks produced by 35 students and 35 families tracked for one week in Delft, acquired by the Sensing the City project, responsible teacher : Stefan van der Spek, TU Delft, (c) 2013.

Our human brain facilitates our movement in space and time. We built a spatio-temporal cognitive map of our (built) environment. Either by physically visiting the location or by using aids such as maps, 3D models and other representations. Emotion adds personal values to the map. Spaces become places with a meaning: nodes or stepping stones on the way from origin to destination. Highlights in the city become landmarks: beacons or location-referenced identifiable objects. We all have our own, unique map in our minds, just like Google builds a personalised representation of the map for you based on search-engine entries, browsing behaviour and physical movement. But, we also have many elements in common. Our brain is the starting point of understanding our movement.

In the lecture I will discuss the relation between movement and the cognitive system, between actual movement and structure offered. Space Syntax (Hillier) uses the spatial layout of infrastructures to determine the potential use. Three-step analysis (De Bois) is based on the limitations of the human brain. Can we reveal the logic of our movement and translate this into design of smarter cities?

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Submitted abstracts

Gaze bias during unaided wayfinding - Individual spatial decision-making and the space syntax approach at street corners.

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Keywords: *wayfinding, eye tracking, space syntax, spatial cognition, real world*

My research investigates the role of spatial configuration on individual spatial decision-making. Over 100 participants take part in laboratory wayfinding experiments based on real-world images of street corners, using fixed and mobile eye trackers. Participants are asked to perform directed and undirected spatial tasks; stimulus-derived and task-related viewing patterns are accounted for. Responses to the spatial tasks are tested for task-related bias against responses in non-spatial tasks (recall, free viewing, and controlled search).

The evidence reveals that, during wayfinding, participants choose the more connected street, measurable with space syntax variables of relative street connectivity (Emo, 2014). Four space syntax variables are used: integration and choice at global and local scales. The resulting measure allows decisions made by individuals to be related directly to the space syntax analysis of spatial morphology. The fixation data allows for an investigation of how wayfinding choices and gaze bias may be linked.

Viewing behaviour during the spatial tasks reveals areas of particular interest at each path alternative; these correspond to structural information in the built environment. A measure for identifying the location of such areas is proposed: "choice zones" (Emo, submitted). Choice zones are computed algorithmically, and are based on space-geometric measures visible in the scene. Choice zones offer a greater scope than existing measures because they are based on information visible in the real world; it is therefore possible to compute choice zones for images of different reference classes (eg. those with varying horizon or sky lines).



Figure 1: Example distribution of fixations of all participants for one stimulus during wayfinding. Areas of interest based on the spatial geometry of the scene, known as "choice zones", identify the main fixation clusters for each path alternative.

The resulting measure has important implications for optimal routing and urban design, identifying those areas of the visual field that contain the most relevant environmental information pertaining to wayfinding.

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Space, Time and Energy in Dismounted Navigation

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Keywords: *Navigation, Routing Algorithms, Energy Expenditure, GPS trajectories, Mobility*

Navigation on foot through the wilderness is practiced by hikers, search and rescue workers, firefighters, members of the military, and many others. The human dynamics of foot-based navigation are critical to understanding individual capabilities, opportunities, requirements, and risk. Models of energy expenditure for dismounted (no horse or vehicle) navigation are not adequate to assist users during route planning and logistical estimation. Improving our understanding of calorie consumption during dismounted land navigation will provide a variety of benefits. Hikers will be able to estimate caloric needs based on trail choice. Search and rescue will improve load planning and routing. Uses of an energy expenditure model for on-foot navigation are numerous.

One of the specific focuses of this research is military land navigation. Military land navigation is a basic skill required of every Soldier and Marine. It is taught at each form of individual basic training, and during all US Army leadership schools. One of the major components of land navigation is route selection. Route selection is an element of every military operation involving dismounted troops. There are many geospatial tools available to assist Soldiers and Marines during route selection (ArcGIS Military Analyst, among others). However, no validated tools address the variable of consumed energy. Energy consumption prediction, and exhaustion avoidance, is critical when planning military operations and patrols. The omission

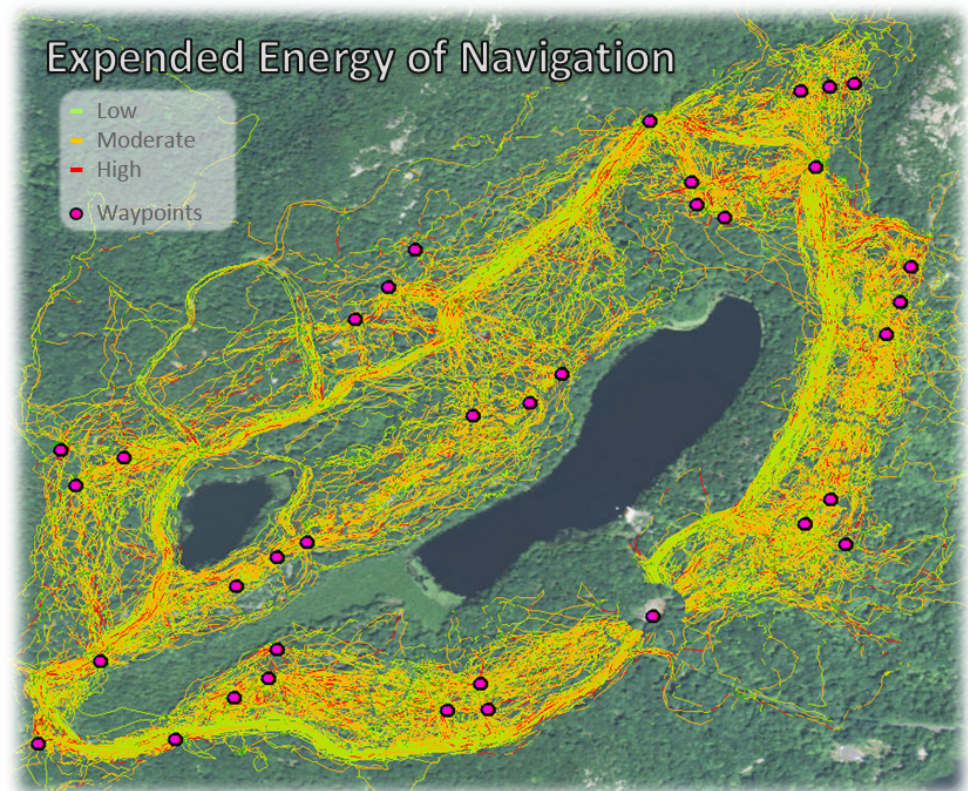


Figure 1: GPS Trajectories of 200 subjects conducting navigation training at the United States Military Academy. this graphic depicts initial estimates of human energy expenditure over varying terrain type.

of tools that provide route planning assistance based on potential exhaustion leaves a gap in current military capability.

This research collected energy expenditure estimates of Soldiers while they navigated on foot over hilly, wooded terrain by attaching biosensors to the subjects. The estimates provide an opportunity to model the contribution of both individual and terrain factors to energy expenditure during dismounted navigation. In-progress analysis of slope, land cover, distance traveled, sex, fitness and BMI will allow for statistical modeling of how human energy is expended while navigating through wooded terrain. Knowledge of the influences contributing to energy expenditure provide a basis for assessing and improving current GIS routing tools. Improving routing algorithms and geospatial tools for the route planner will greatly improve our current capabilities.

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A study on the evaluation of the optimal route for wheelchair users

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We are targeting wheelchair users to provide optimal travel routes that place the least physical and psychological burden on disabled citizens while moving in the urban area. Several researches have been conducting studies on navigation of wheelchair individuals [1][3]. They produced optimum routes that have the fewest barriers on their path. They used several factors that are considered barriers for wheelchair users from results of the interview survey, the targeting area survey and the users' physical and psychological features. However, it is doubtful that the optimum route produced based on those factors was the best route from the users' point of view, since some wheelchair users reported, "I prefer the shortest route even though the optimum route has fewer pedestrians and is easier to navigate" [2]. In this study we wanted to find out what criteria defines the best route and also to devise a way to compare the best route and optimum candidate route.

To evaluate the optimal route, we took an assumption that the route chosen by a person that is very familiar with the area would be the best route for that person in a given context (physical abilities, transport mode, motivation etc.). Accordingly we term this kind of individualized route as 'user route (best route)' and the computed best-candidate route as 'optimal route'. We have developed a method to find user route by improving the consistency between user route and computed route in a target area. The process includes:

1. Choose a target area and survey road data

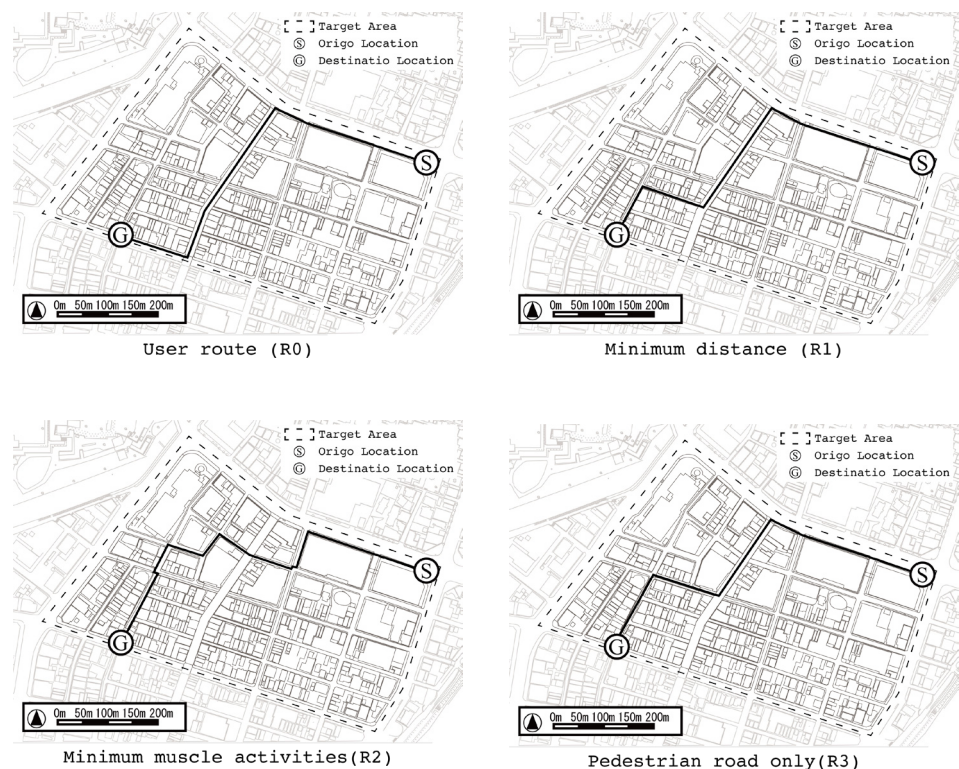


Figure 1 : Example routes which were used in workshops

2. Get user routes for several Origin/Destination locations and evaluate the similarity with computed optimal route between the same set of OD's.
3. Let wheelchair users travel the counterpart sets of 'user' and 'optimal' routes and ask for their opinion in a workshop

A model area in Kumamoto city that encompasses a part of the central shopping arcade was selected. The area is approximately 17.5 ha and includes the city office, two major shopping buildings, and two main streets. We chose streets in the model area accessible to wheelchair users represented by a digital network constituted by 214 nodes and 268 links. Then, a detailed survey of each link was conducted. The survey included about 20 attributes including length and width of the street, paving materials, and so on. In-situ we measured muscle action potential for six points on both arms, wheelchair vibration and tilts in 3 axis during wheelchair motion.

Then, we collected 'user route' from 8 wheelchair users. We asked them to draw the route on the area map. Afterwards, we used computed routes with 'minimum distance (R1)', 'minimum muscle activities (R2)', 'pedestrian road only (R3)' to compare with 'user route (R0)'. Wheelchair users traveled the routes (R0, R1, R2 and R3) and we have discussed their opinions for each route in workshops. (Fig. 1 is showing example routes of each).

To conclude, we have conducted a survey to find the criteria for the best route and compared the best route to the 'optimum route' in a field study. From the survey we found that wheelchair users prefer wider streets because it is easier to pass around pedestrians. They hesitate to use streets that have steps in between car and pedestrian roads. Also for most streets they felt that a horizontal slope is more difficult than a vertical slope. In the workshop, a wheelchair user felt in danger when they were moving towards a crossing of a side street and main road because a street pile and nearby walls created a blind spot. This workshop suggested that there are factors that even wheelchair users do not usually consider or realize when choosing a route. We believe the study method we have chosen has helped to find some of the previously unknown factors that affect the computation of best routes.

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Adjusting for Cognitive and Spatial Biases of VGI: The Case of Perceived Risks in Urban Cycling.

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Keywords: *volunteered geographic information, risk perception, gaze behaviour, isovist, urban cycling*

The increasing number of opportunities to collect Volunteered Geographic Information (VGI) creates new means to plan, manage and improve our cities. However, utilisation of VGI in urban planning and policy making is slow, mainly due to controversies surrounding its reliability and representativeness (Goodchild and Li, 2012; Brown and Kyttä, 2014). In particular, the data visible to the planner/researcher as an output of a VGI project is aggregated from multiple contributions of a number of users - each acting under different circumstances, with varying levels of commitment or expertise, and following a chain of very different individual experiences. Additionally, VGI contributions are typically performed in retrospect (and not on-the-spot), which might result in judgment being influenced by the interaction with other online map users (e.g. high popularity/visibility of some already existing VGI entries).

We propose a method for validating VGI contributions based on a data set collected by a major German newspaper in the city of Munich (Germany). Respondents were asked to mark and textually describe locations considered dangerous for cycling on an online map of their city. Users were also able to 'like' the already existing comments. The project generated over 5000 entries within a week. On the basis of this data set, we conducted an exploratory case study investigating the impacts of spatial and cognitive biases on the validity of VGI. A sample of 20 locations was selected (e.g. those receiving high number of VGI 'likes'). A 360-degree panoramic view of these locations was sourced from Google StreetView and presented to a group of 15 participants through a head-mounted display (Oculus Rift 2). Participants were asked to rate the subjective risk associated with the given



Figure 1: Comparing Volunteered Geographic Information on cycling danger with subjective risk perception in immersive video set-up.

location as well as grade their agreement with the textual description derived from the original VGI contribution.

The results are analysed with respect to the viewing behaviour of the participants (measured by the dynamism and distribution of head movement) and spatial complexity of the area visible from the respective location (measured by how 'spiky', 'circular', large or small the isovist of the given intersection is; Benedikt, 1979; Wiener et al., 2007). The main focus of the analysis is the degree to which participants in a laboratory-based study agree with the VGI data. We hypothesise that some spatial characteristics of the intersections are likely to result in similar perception of risk in both cases. We claim that instances for which VGI 'likes' do not correlate with the perceptual judgement performed in-the-lab are those especially informative in regard to potential biases of any VGI project - such as their dependence on popularity of a given location or social processes moderating the interactions of online map users. Evidence supporting this assumption would provide further insight into which contributions of VGI projects are valid (and thus for example useful for urban planning), and which contributions require additional attention.

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Navigating three-dimensional museum environments

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Keywords: *Museum, three-dimensionality, atria, navigation, spatial cognition, Space Syntax, agents*

The relationship between museums' layouts and visitors' explorations has been extensively studied. However, previous studies rarely focused upon the actual impact of atria on human navigation. To understand this interaction entails answering the following research question: which is the impact of three-dimensional architectural design and atria on navigation and cognition? The question is examined by the comparative study of the Ashmolean Museum in Oxford, the Museum of Scotland in Edinburgh and the Acropolis Museum in Athens.

The analysis, stemming from Space Syntax methods, space use observations and agent simulations, shows that significant differences in real and simulated movement result from the varying spatial positioning, role and character of the voids. In

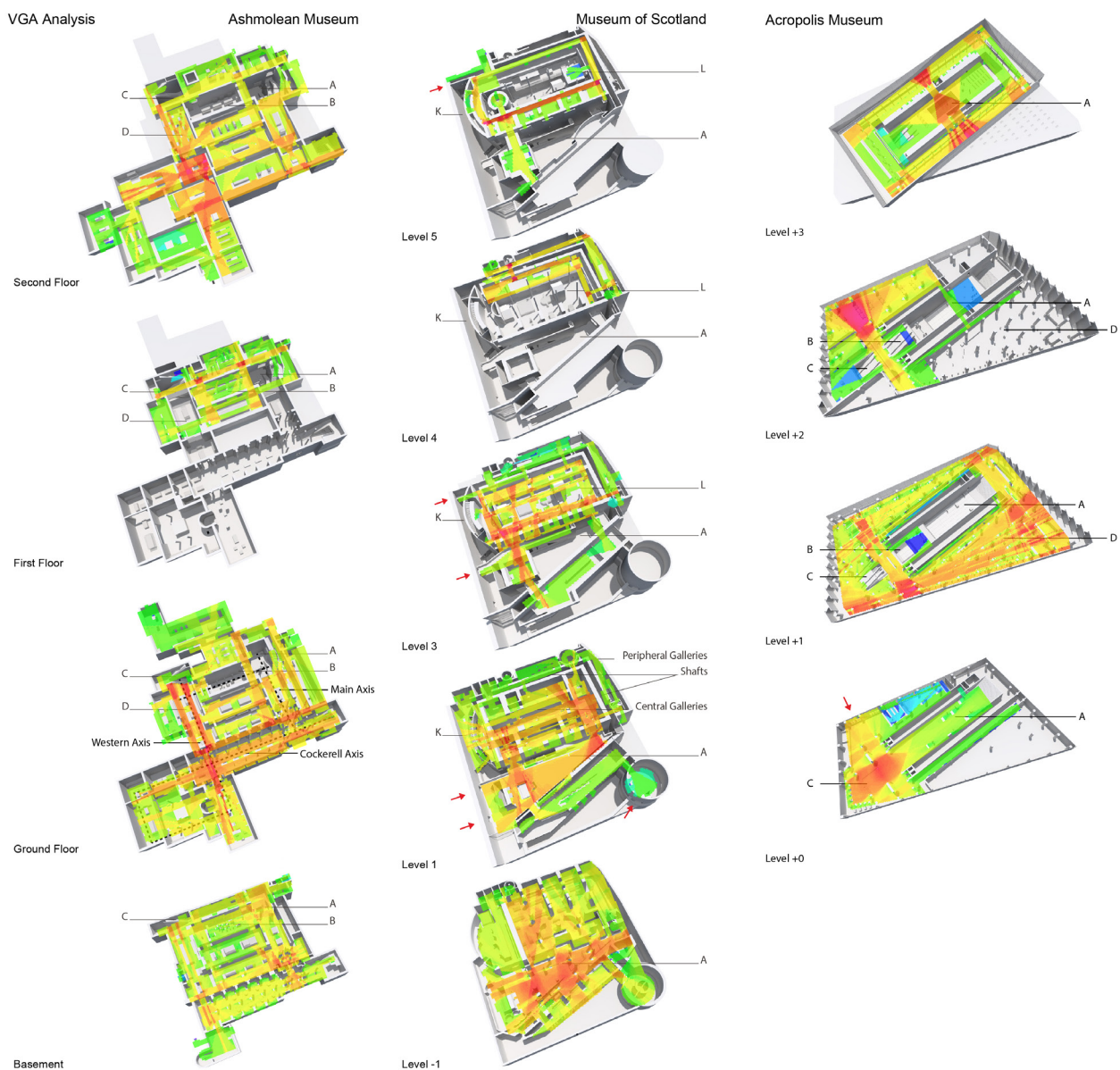


Figure 1: 3D museum models overlaid with Visibility Graph Analysis (VGA).

particular, Justified Graphs describe the hierarchical relationships between the atria in terms of the degree of movement control they play. Isovisits illustrate that the voids in the Ashmolean create a strong, visually unified core compared to the Museum of Scotland. In the Acropolis, the main atria are not visually interlinked creating a sense of separation between them. Axial and VGA analysis, highlight Ashmolean's integrated visual core feeding into visitors' perception during navigation. Differences between axial and VGA integration in the Museum of Scotland suggest a disjunction between the linear structure of circulation and the visual structure of the museum. In the Acropolis Museum, the interplay between permeability and visibility enhances the vertical circulation and prescribes the succession of galleries. Observed movement shows that Mather uses a set of atria to integrate spaces, assigning different degrees of strength between them but all equally participating in structuring navigation. On the other hand, Benson and Forsyth, use the voids as compositional devices of symbolic strength, vary their shape and size and establish hierarchical relationships between them affecting the ways people navigate. Similarly, in the Acropolis Museum, the main atria present hierarchical relationships introducing visitors to the three-dimensional structure of the museum and enhance vertical movement. The agent analysis visualises differences between the two-dimensional simulated and the three-dimensional real movement strengthening the hypothesis that certain spatial decisions are affected by the third dimension.

To conclude, variability in spatial behaviour derives from the impact of the third dimension, assigning different identities and orientating capacities to the atria and the museums. The atria in the Ashmolean act as key reference points of the circulation and conceptual structure, creating a sense of visual unity and interfacing the museological with the architectural experience. In the Museum of Scotland the voids act as strong media for architectural expression shaping the compositional structure of the museum, as a more controlled, protected and sculpted environment enhancing a rich three-dimensional spatial experience. In the Acropolis Museum, atria are used to enhance the didactic and museological character of the museum by shaping three-dimensional circulation paths around them.

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MoMe: a context-sensitive mobile application to research spatial perception and behaviour

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Keywords: urban planning and health, environmental stressors, perception, behaviour

Which environmental and spatial parameters influence the perception of the built environment and its users' behaviour? In this abstract, the authors present the prototype MoMe, a context-sensitive mobile application developed as a research tool to assess spatial perception and behaviour in urban open spaces. The aim of the prototype is to record quantitative and qualitative data by making use of the context-awareness of mobile devices. Thanks to the interactive nature of mobile applications, the proposed framework can be used to guide and engage users in a specific manner with the built environment, which can be choreographed according to research questions in a somewhat flexible or even playful way. A conceptual framework for the development and evaluation of the prototype is presented here and is underlined with the results and experiences of a proof of concept setup.

The case study took place in Darmstadt, Germany. The prototype was tested in one afternoon on-site by a group of visiting students. Each one received a smartphone with the android application MoMe, which guided them through the selected open spaces, while it recorded data about navigation (GPS tracks and waypoints with time-stamp), and perception (photos and ratings) throughout the experience.

The three open spaces were selected because of their importance to the everyday urban life and contrasting spatial characteristics: two main public squares in the city, which are central transportation hubs – transitional spaces – as well, and an enclosed park in the city centre. Participants were asked to search for stressful and relaxing areas within the open spaces, take photographs of distinctively stressful or relaxing elements or setups, and rate the space according to eight core aspects of environmental and behavioural experience. This last part was done by giving the variables a value in a ten-step semantic differential scale. The analysis was focused on navigation behaviour, user perception of open spaces, as well as emotional state and satisfaction with the application, last two assessed through surveys.



The work presents how an interactive survey, which gathers qualitative data in situ about spatial perception, and data recording on spatial perception and behaviour, are being connected in the prototype. The recorded data, e.g. tracing real-time navigation and the chosen stressful or relaxing areas within the open spaces, among others, was visualized in QGIS. The researchers also outline a set of “portraits” with statements about spatial perception for each area within the open spaces with the gained data, corroborating the relevance of certain environmental and spatial parameters. The recorded qualitative data is linked to the recorded quantitative data and further quantitative spatial analysis, including a space syntax analysis conducted in previous research. The data has been visualized, complementing an analytical urban model of the city, and hasn’t been yet thoroughly analysed.

This makes a contribution to the field by suggesting and evaluating a novel method of data recording including context-sensitive mobile applications. It endorses ways to link qualitative data to objective spatial analysis and its visualization, which can be made available to urban planners, citizens and stakeholders and encourage a discussion about the potentials of the data for planning, administration and urban everyday life.

While the focus was on spatial perception and stress perception, other behavioural data has to be the focus of further research.

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Exploring cities as visuospatial networks of pedestrian movement

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Keywords: pedestrians, urban planning and design, spatial cognition, spatial networks, urban activity location, visibility graphs, complex networks

We investigate human pedestrian behavior in relation to the distribution of urban retail activities by means of visibility patterns created within the urban layout. A city is comprehended as a chain of pedestrian navigational decisions that form mathematical graphs (or networks) based on its visuospatial properties (Natapov et al, 2013). We create two graphs: a street network visibility graph and a functional visibility graph. The last includes functional points of interest, i.e. predefined urban activities as an additional type of the graph node. In this study we focus on food and drink public facilities in the historical district of Tel Aviv-Yafo, these activities are among the most probable navigational targets for pedestrians who happen to be in the area (figure 1).

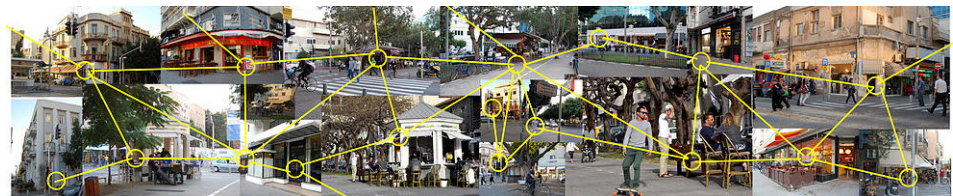


Figure 1: Potential navigational targets in the case study area -cafés, restaurants, and other food and drink public facilities.

Representation of the case study as a graph allows us to apply analytical models from network theory in order to investigate the graph's structural properties (Barabasi and Albert, 1999; Erdős and Renyi, 1959). Small-world and scale-free models are carried out to examine global properties and organization of the network and to compare the two constructed graphs. Our findings illustrate that both the street visibility graph and the functional visibility graph possess small-world properties. A small-world network is a type of mathematical graph in which most nodes are not neighbors of one another, however they can be reached from every other by a small number of steps. Furthermore, the results reveal that the distribution of visibility lines in the functional graph behaves according to the power law. Small-world properties and power law distribution reflect overall network organization and imply a self-organization capability of the network. Similar properties are found in many real-world phenomena, including food chains, electric power grids, neuron networks, voter networks, telephone call graphs, and social networks. Such network organization is an outcome of growth dynamics, it uncovers the rules behind efficiency and robustness of urban environment and illuminates forces that link human spatial cognition to urban development. The results of the study may be applied to the adaptation and enhancement of spatial tools for design of sustainable and walkable urban environments.

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Movement, successive presentation and environmental structure and their influence on spatial memory in vista and environmental space

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Keywords: *Vista space, environmental space, object location, judgement of relative direction, object placement*

A vista space (VS), e.g., a room, is perceived from one vantage point, whereas an environmental space (ES), e.g., a building, is experienced successively during movement. Participants learned the same object layout by walking through multiple corridors (ES) or within a differently oriented room (VS). In four VS conditions they either learned a fully or a successively visible object layout, and either from a static position or by walking through the environment along a path, mirroring the translation in ES. Afterwards, participants pointed between object locations in different body orientations and reproduced the object layout. Pointing latency in ES increased with the number of corridors to the target and pointing performance was best along corridor-based orientations. In VS conditions latency did not increase with distance and pointing performance was best along room-based orientations, which were oblique to corridor and walking orientations. Furthermore, ES learners arranged the layout in the order they experienced the objects, and less so VS learners. Most beneficial pointing orientations, distance and order effects suggest that spatial memory in ES is qualitatively different from spatial memory in VS and that differences in the visible

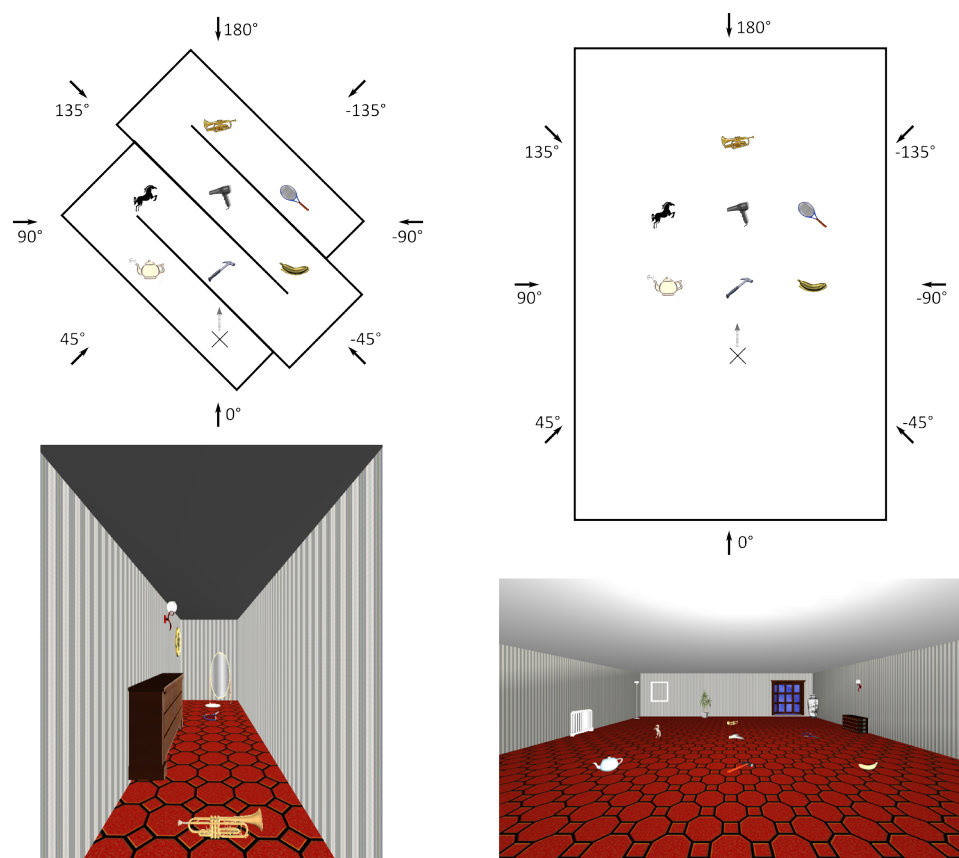


Figure 1. Layout from a birdseye perspective and participants view from within two of the tested environments. Left: ES condition. Right: VS environment from a static point of view and the whole layout visible. Grey arrows above the Xs indicate the initial view upon the environment. (Illustration: Marianne Strickrodt/Max Planck Institute for Biological Cybernetics)

environment (spatial structure) rather than movement or successive presentation are responsible for that. Our results are in line with the dissociation of vista and environmental space as postulated by Montello (1993). Furthermore, our study provides a behavioral foundation for the application of isovists when conducting visual integration analysis, which is one module of the space syntax approach (e.g., Hillier, 1999).

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